

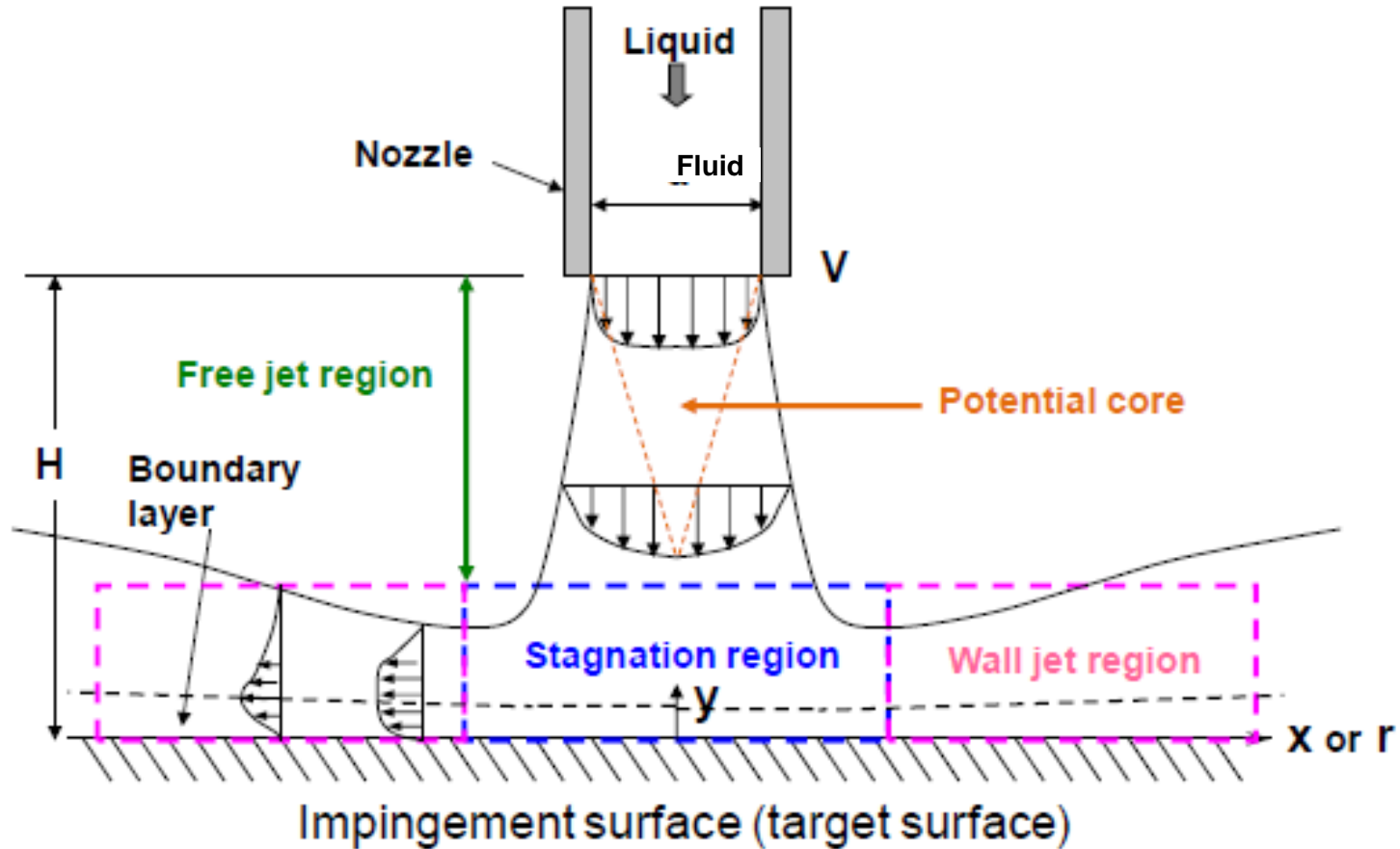


# **NUMERICAL INVESTIGATION OF HEAT TRANSFER FROM A PLANE SURFACE DUE TO ANNULAR SWIRLING TURBULENT JET IMPINGEMENT**

**Farhana Afroz and Muhammad A.R. Sharif**  
**Aerospace Engineering and Mechanics Department**  
**The University of Alabama**  
**Tuscaloosa, Alabama, USA**



# Impinging Jet Configuration



## Plain surface impingement



# Annular Jet Configuration

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*W. T. Chan and N. W. M. Ko*

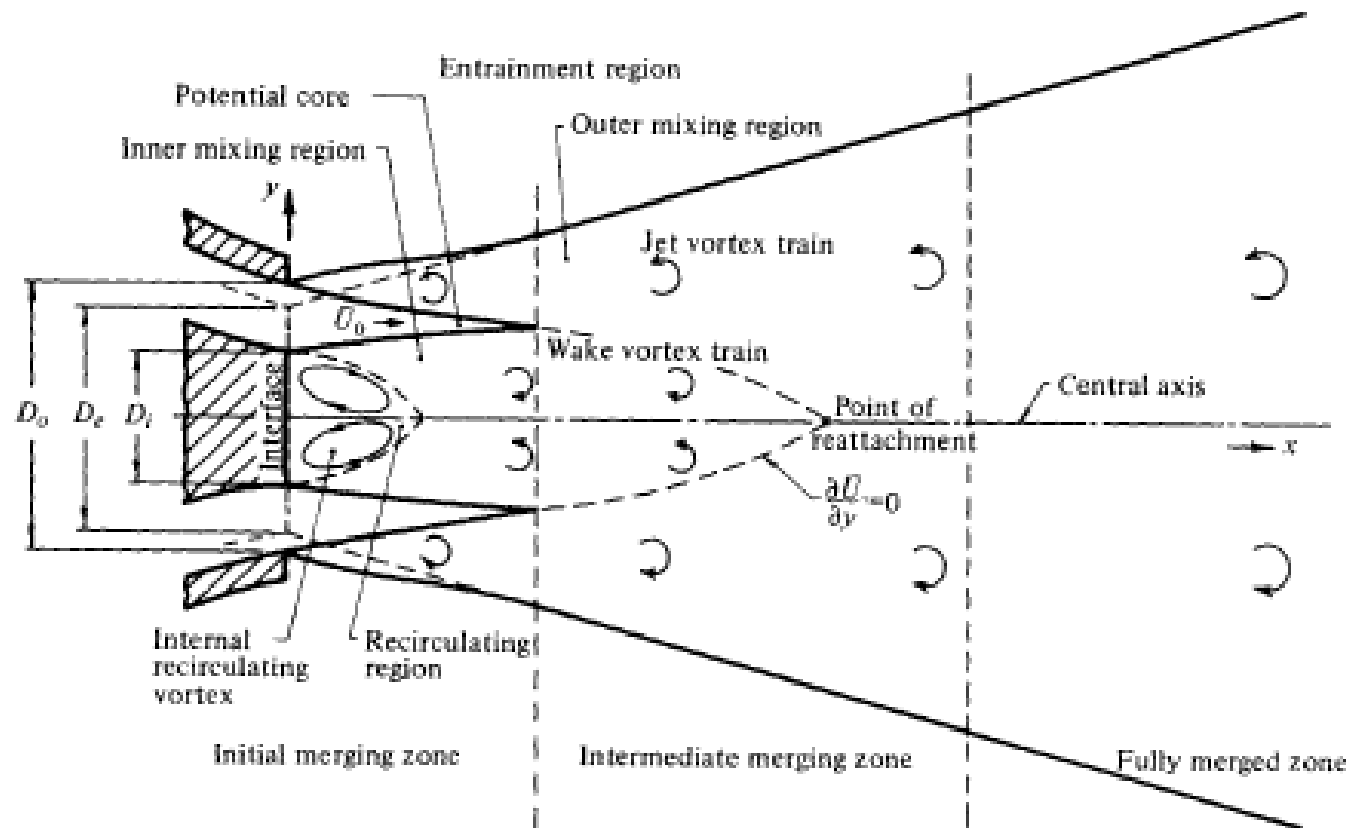


FIGURE 1. Schematic diagram of basic annular jet.



# INTRODUCTION

- Cooling of hot surfaces by impinging jets is an effective and age-old cooling method.
- Due to high rates of localized heat transfer, impinging jet flows are employed in a wide variety of applications of practical interest.
- Numerous studies have been conducted on impingement jets over the years with various combinations of geometric and flow configurations.
- Major sub-group of these studies include non-swirling and swirling round and annular jet impingement heat transfer.



# INTRODUCTION (contd.)

- Swirl alters the jet spreading rate, which in turn alters the heat transfer characteristics.
- The jet growth, ambient fluid entrainment, jet decay, etc., is influenced by the swirl.
- Published studies dealing with swirling annular impinging jet are not plentiful.
- Important to investigate the swirling jet impingement heat transfer.
- Understand the overall flow physics and the pros and cons of using swirl.



# INTRODUCTION (contd.)

- In this study, the heat transfer from an isothermal hot circular surface due to non-swirling and swirling turbulent annular impinging open jets has been investigated.
- The flow is investigated for a range of the swirl intensity and jet-to-impingement surface distance at a specific Reynolds number.

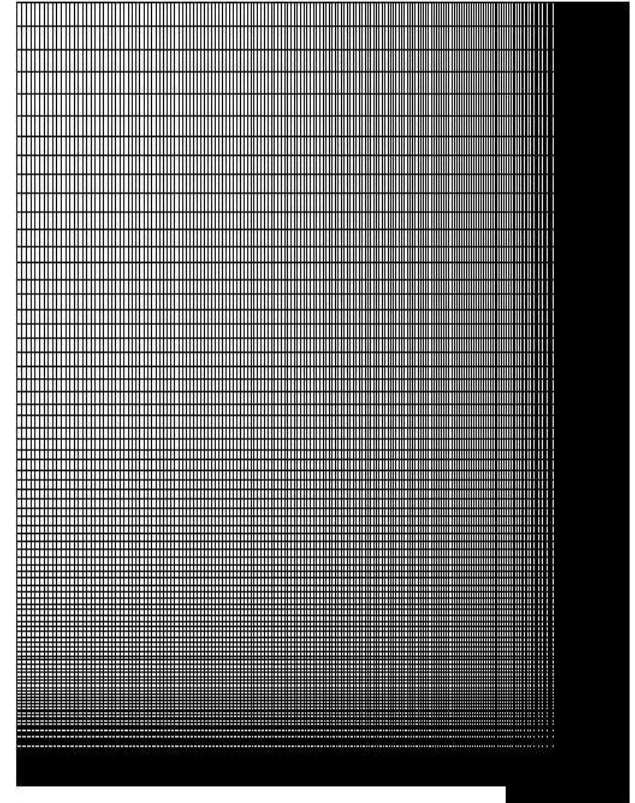
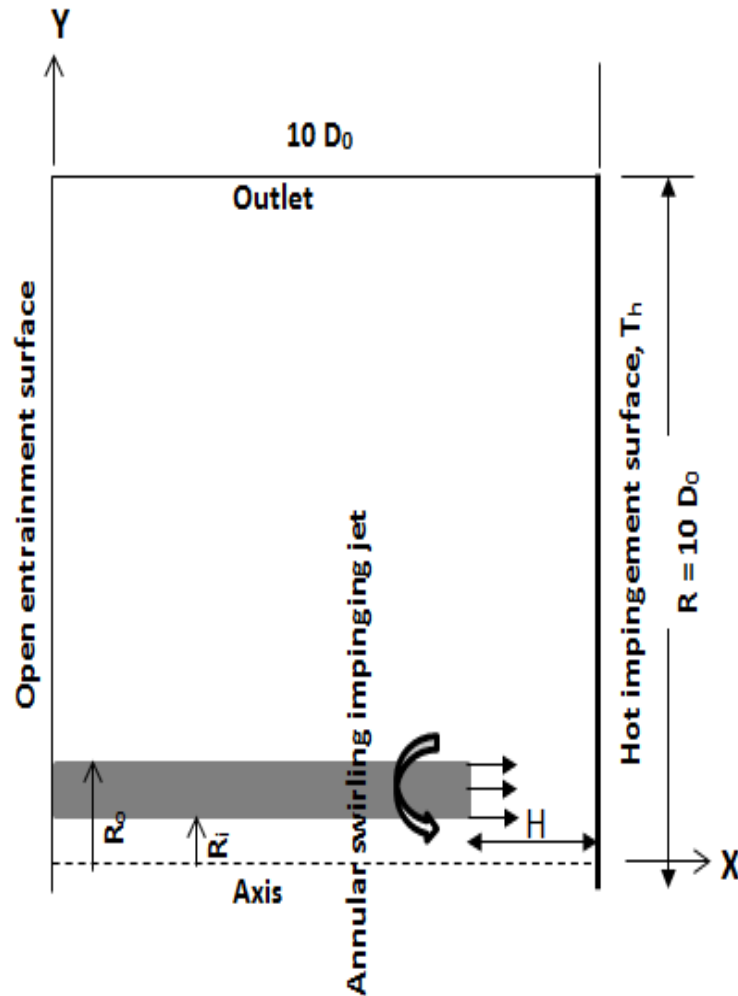


# NUMERICAL PROCESS

- Computations are done using the ANSYS FLUENT CFD code.
- The realizable k- $\epsilon$  turbulence model with enhanced wall function and a very fine mesh near the wall is used in the computation.
- The mesh resolution was chosen after systematic mesh refinement study and validation against experimental data.
- Conservation equations for mass, momentum, and energy are solved.
- Second order upwind scheme for the convection terms and central differencing for the diffusion terms.
- The SIMPLE method for the pressure-velocity coupling.
- The governing equations are solved sequentially.
- Converged when the normalized residual falls below  $10^{-6}$  for all variables.



# PROBLEM GEOMETRY







# PROBLEM PARAMETERS

- Jet Diameter:  $D_o = 0.03$  m,  $D_i = 0.0225$  m,  $D_i/D_o = 0.75$ .
- Jet exit Reynolds number,  $Re = 5,000$ .
- Prandtl number,  $Pr = 0.71$  (air).
- Jet to impingement surface spacing ( $H/D_o$ ): 0.5 - 8.
- Swirl strength or swirl number,  $SW = 0, 0.21, 0.44, 0.77$ , and 1.
- Various combinations of these parameters are considered.
- Total of 40 combinations of  $H/D_o$  and  $SW$  are considered.



# GOVERNING EQUATIONS

- **Continuity equation**

- $$\frac{\partial u}{\partial x} + \frac{1}{y} \frac{\partial(yv)}{\partial y} = 0 \quad (1)$$

- **Momentum equation**

- $$\frac{\partial u^2}{\partial x} + \frac{1}{y} \frac{\partial(yvu)}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\partial(\tau_{xx})}{\partial x} + \frac{1}{y} \frac{\partial(\tau_{xy})}{\partial y} \quad (2)$$

- $$\frac{\partial(uv)}{\partial x} + \frac{1}{y} \frac{\partial(yv^2)}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \frac{\partial(\tau_{xy})}{\partial x} + \frac{1}{y} \frac{\partial(y\tau_{yy})}{\partial y} - \frac{\tau_{zz}}{y} \quad (3)$$

- $$\frac{\partial(uw)}{\partial x} + \frac{1}{y} \frac{\partial(yvw)}{\partial y} - \frac{vw}{y} = \frac{\partial(\tau_{xz})}{\partial x} + \frac{1}{y^2} \frac{\partial(y^2\tau_{yz})}{\partial y} \quad (4)$$

- **Energy equation**

- $$\frac{\partial(uT)}{\partial x} + \frac{1}{y} \frac{\partial(yvT)}{\partial y} = \frac{1}{\rho c_p} \left[ \frac{\partial(q_x)}{\partial x} + \frac{1}{y} \frac{\partial(yq_y)}{\partial y} \right] \quad (5)$$



# BOUNDARY CONDITIONS

- Uniform axial velocity, solid body rotation swirl velocity, and cold temperature (300 K) at the jet inlet.
- No-slip at all wall and isothermally hot boundary condition (315 K) for the impingement surface.
- Constant pressure-outlet condition at the left entrainment boundary and at the outlet section where the variables are extrapolated from inside.



# SWIRL STRENGTH

$$SW = \frac{\text{Azimuthal momentum}}{\text{Axial momentum}}$$

$$SW = \frac{\int_{jet\ inlet} \rho u w (y dy)}{\int_{jet\ inlet} \rho u u (y dy)}$$

$$SW = \frac{\omega}{U_{in}} \frac{\int_{D_i/2}^{D_o/2} y^2 dy}{\int_{D_i/2}^{D_o/2} y dy} = \frac{1}{3} \frac{\omega (D_o - D_i)}{U_{in}}$$

$$\omega = 3 (SW) U_{in} / (D_o - D_i)$$



# RESULTS (SW = 0)

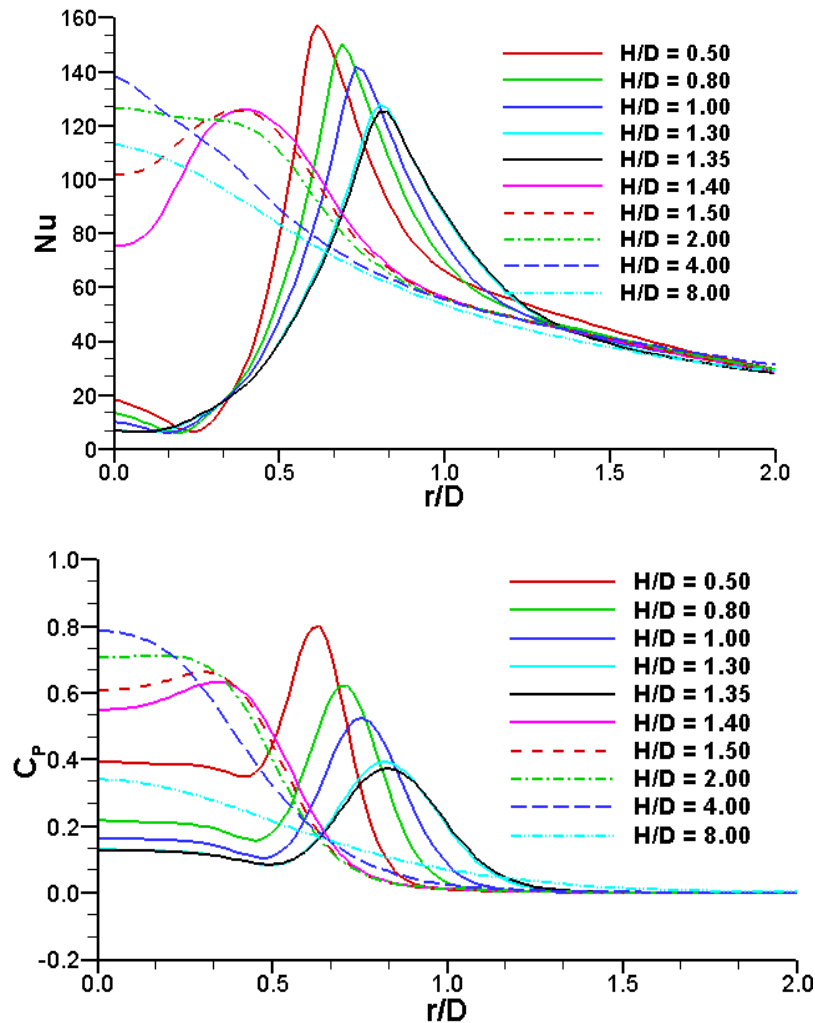
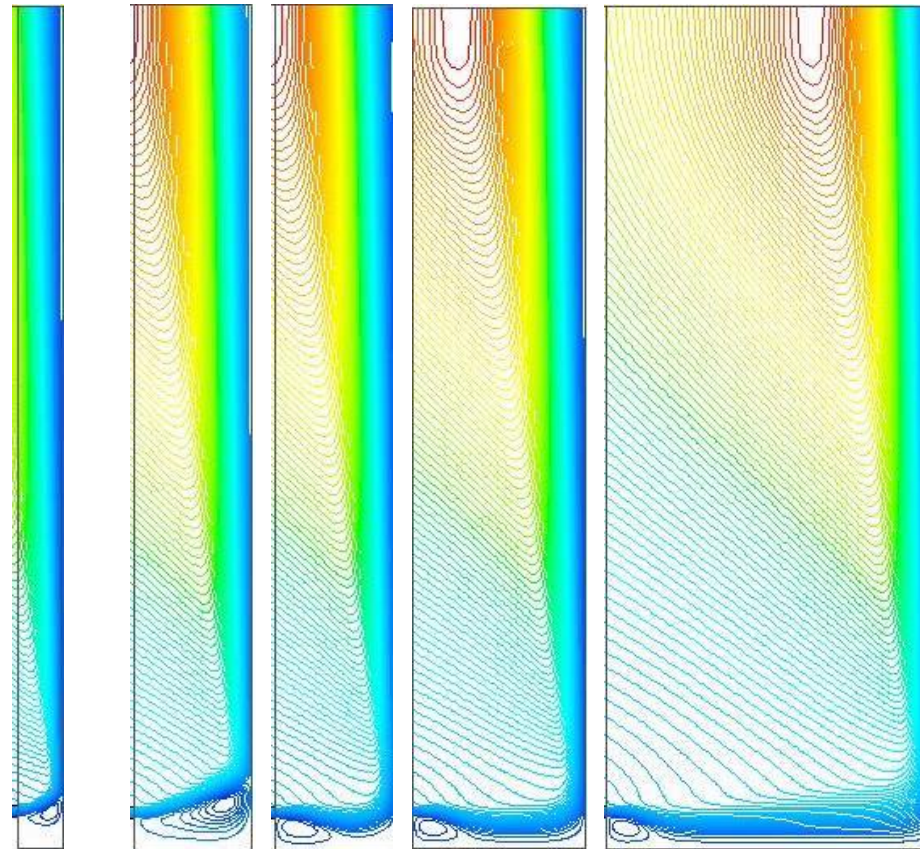


Figure 1. Local Nusselt number and pressure coefficient along radial direction on the hot plate at different jet-to-plate separation distance,  $H/D$  for  $Re = 5,000$ ,  $D_i/D_o = 0.75$ .



# RESULTS (SW = 0) continued



$H/D = 0.5$

$H/D = 1.35$

$H/D = 1.4$

$H/D = 2$

$H/D = 4$

Figure 1. Streamline contour on axial-radial plane for different jet-to-plate separation distance,  $H/D$  for  $Re = 5,000$ ,  $D_i/D_o = 0.75$ .



# RESULTS ( $SW \geq 0$ ) continued

$H/D = 2, 4, 8$

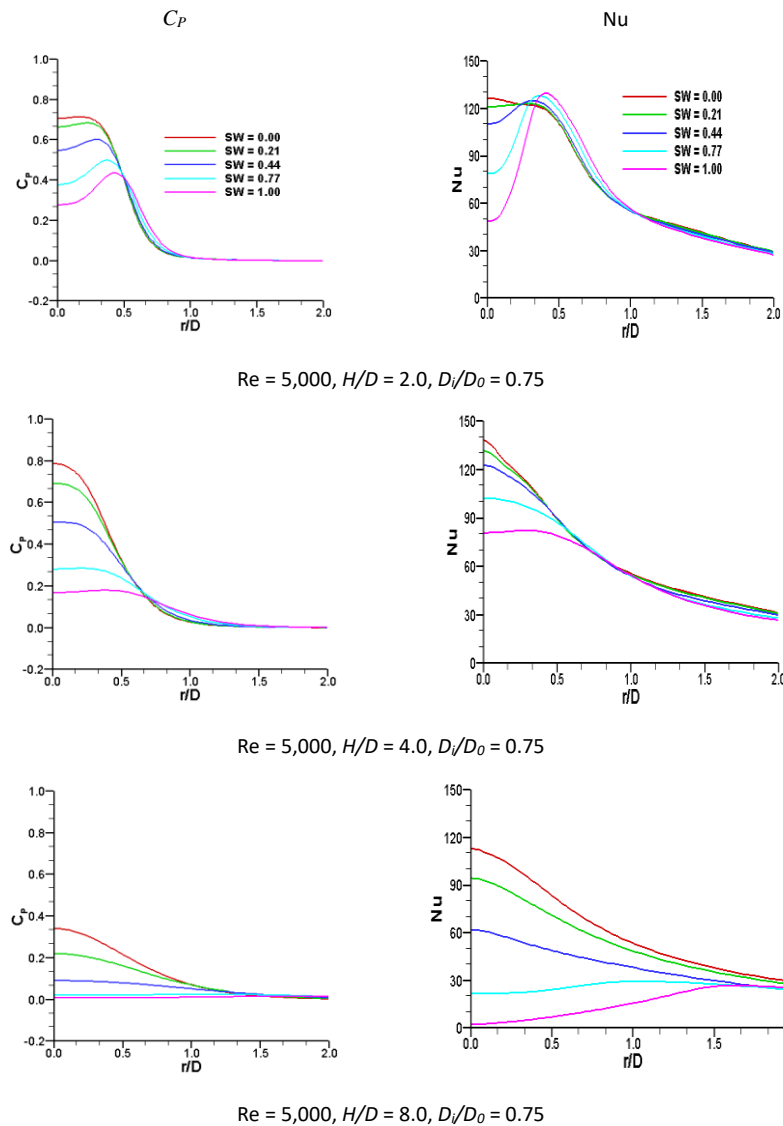


Figure 1. Pressure coefficient and local Nusselt number along radial direction on the hot plate at different jet-to-plate separation distance,  $H/D$ .





# RESULTS ( $SW \geq 0$ ) continued

$H/D = 4$

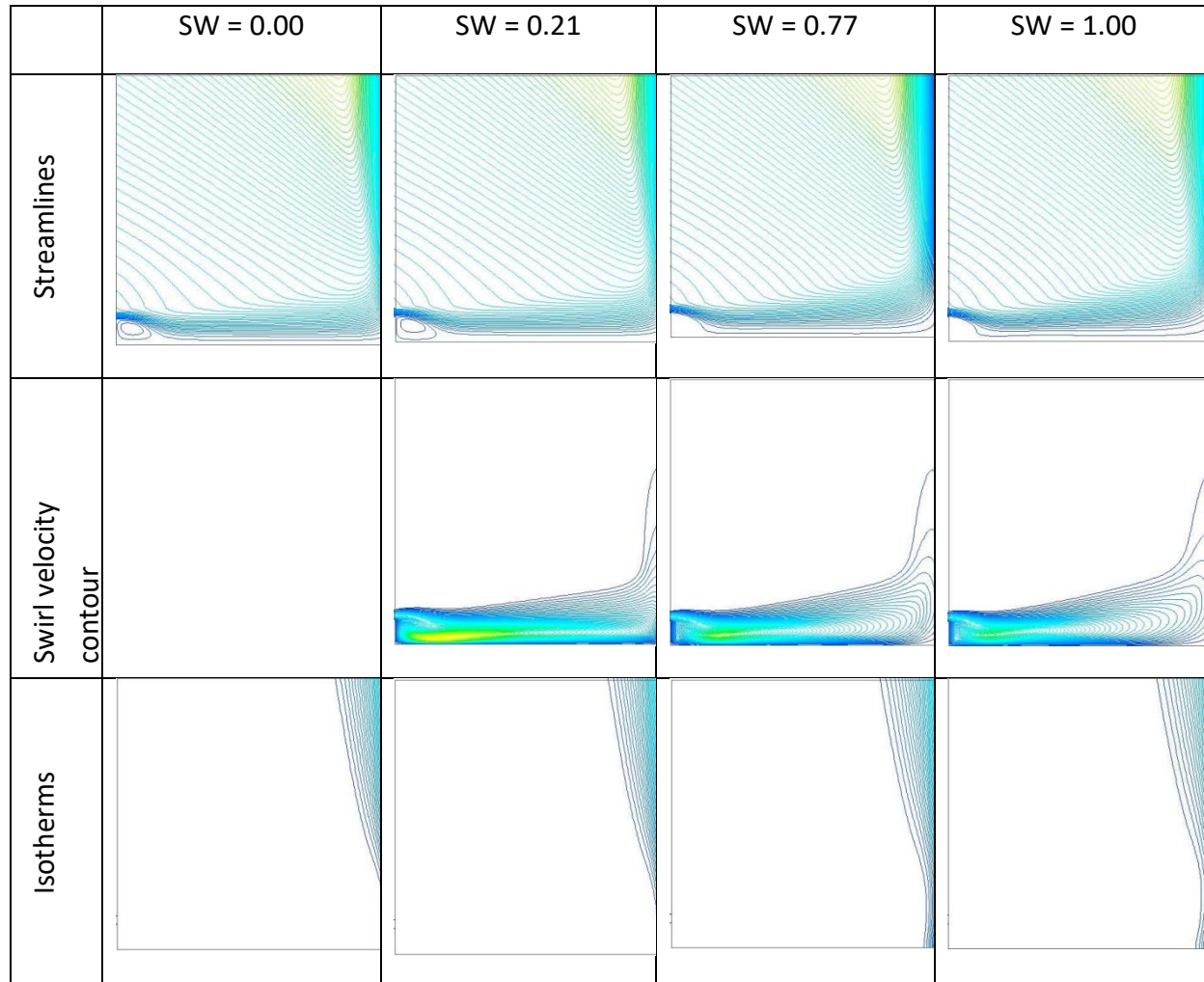


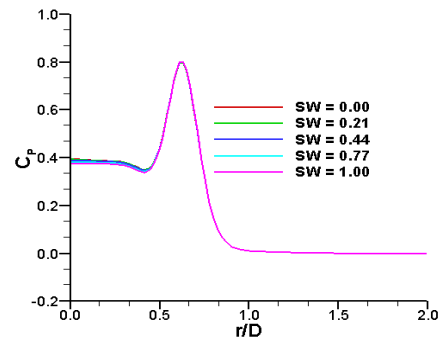
Figure 1. Streamlines, swirl velocity contours, isotherms on axial-radial plane for  $Re = 5,000$ ,  $H/D = 4.0$ ,  $D_i/D_0 = 0.75$ .



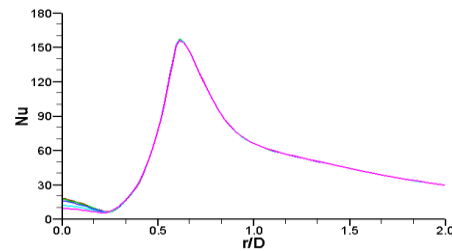


# RESULTS ( $SW \geq 0$ ) continued

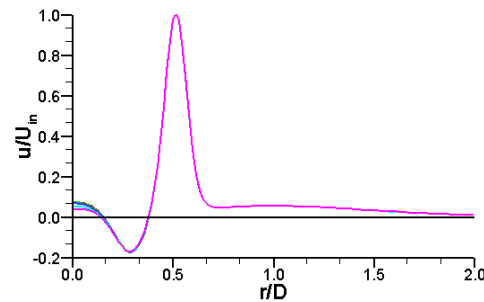
$H/D = 0.5$



(a)



(b)



(c)

Figure 1. Distribution of (a) pressure coefficient, (b) local nusselt number, and (c) axial component of velocity along radial direction hot plate for  $Re = 5,000$ ,  $H/D = 0.5$ ,  $D_i/D_o = 0.75$ .



# RESULTS ( $SW \geq 0$ ) continued

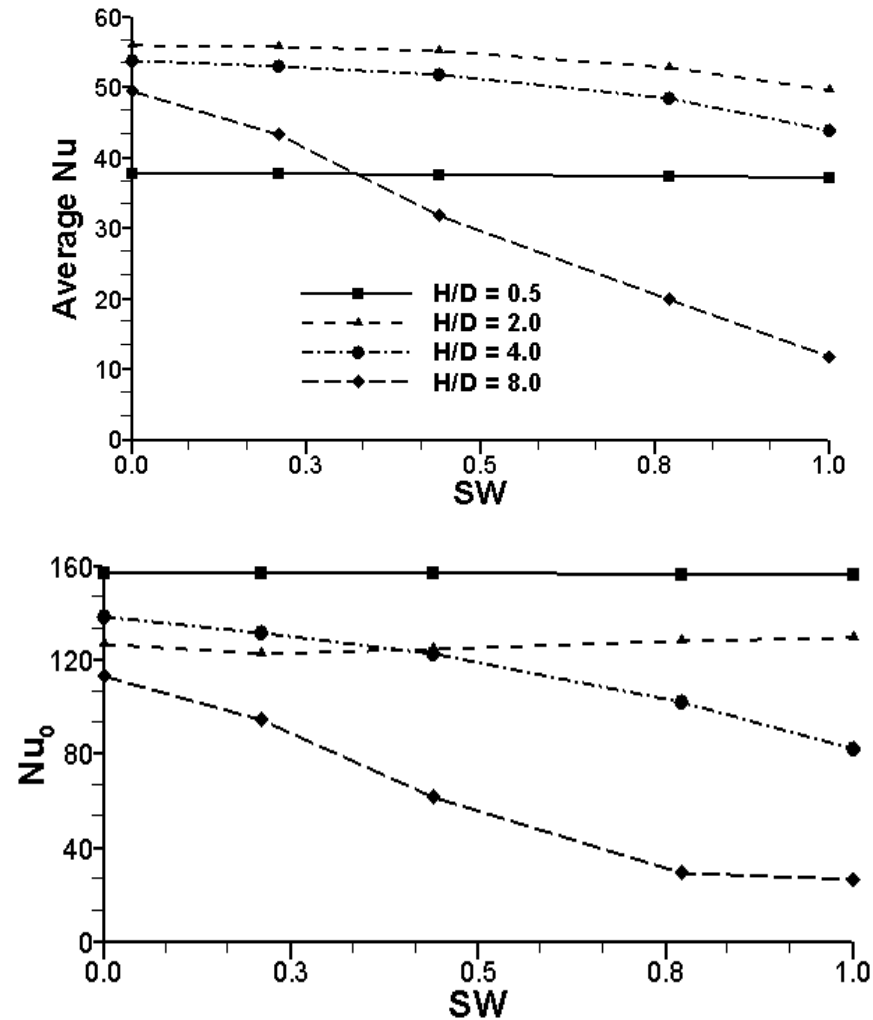


Figure 1. Effect of swirling on variation of average Nusselt number and stagnation point Nusselt number,  $Nu_0$ , for various jet-to-plate separation distances.



# CONCLUSIONS

- Three different jet-to-target separation distance ranges are identified.
- Each range affects flow structure and heat transfer differently.
- Shorter jet-to-target separation distances cause reverse stagnation flow.
- Swirl does not improve the reverse stagnation flow and does not offer any improvement of heat transfer and flow structure.
- Swirl causes the pressure coefficient and Nusselt number distribution more uniform.
- At very large separation distance ( $H/D = 8$ ), higher swirl strength ( $SW \geq 0.77$ ) causes reverse stagnation flow and heat transfer reduces rapidly with increasing swirl strength.
- Studies need to be done for a wider range of Reynolds number and diameter ratio.
- Realistic inlet swirl velocity profile should be used.



**Questions?**

**Thank you.**